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Accuracy of slot dimensions in different types of orthodontic brackets (An *in-vitro* study)

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Abstract
Purpose: To Evaluate the accuracy of the slot size dimension of 0.022-inch slot pre-adjusted MBT bracket system of three different companies.
Methodology: A total of 33 upper left central incisor brackets were divided into 3 equal groups according to their manufacturing companies; (Dentaurum, American Orthodontic and Leone), then they were prepared to be scanned under SEM.
Results: When compared to the standard MBT prescribed values, (Dentaurum) showed the least variance in slot height of the samples, and (American Orthodontics) showed the most variation. For the slot depth, (Dentaurum) had shown least variation and (American Orthodontics) displayed the most variation. Nearly all of the brackets, when assessed for slot depth, were undersized.
Conclusion: It was concluded that the examined brackets' real dimensions differed greatly from what the companies have stated. Between various bracket systems, there was a significant difference in the slot dimensions. *In vivo* studies are recommended to analyze the clinical impact of the inaccuracies found in the bracket dimensions.

Keywords: Orthodontics brackets, slot dimensions, MBT

1. Introduction
Stable functional occlusion and acceptable facial esthetics may be considered among the most important goals of orthodontic treatment. Based on the type of malocclusion and the patient's reported age, these goals are accomplished with either orthodontic or orthopaedic appliances. Using a fixed or removable appliance, teeth can be moved into the proper position for orthodontic treatment. Fixed appliances have better control over tooth movement due to integrated tip, torque, and in & out values, hence, the most crucial component of fixed appliance therapy is orthodontic brackets. The ultimate esthetic result of the treatment is significantly influenced by the tip and torque values integrated into the brackets. These tip and torque settings that have been integrated are known as bracket prescriptions [1].
The fewer additional bends in orthodontic archwires that are required during treatment due to inaccurate bracket adjustments, the shorter the chair duration and less sensitive skill needed. Today, however, numerous industries are competing for the best pre-adjusted bracket system with the correct prescription while maintaining the highest level of production quality.
The literature offers a wide range of methods for measuring slot dimension accuracy. Pin gauges [2], leaf gauges [3], stereomicroscopes [4], electron microscopes [5], profile projectors [6], and micro-hardness tests [7] are among the most often used techniques, yet each has benefits and drawbacks of its own. To overcome the problems of earlier studies, a possible alternative that is more accurate and reliable than the aforementioned approaches is the scanning electron microscope SEM.
Five upper left central incisor bracket slots were measured by Cash *et al.* [8] The findings showed that every bracket slot was large. According to research, there were significant differences in slot geometry and bracket finish standards amongst the bracket groups. Clinicians should be aware that the accidental use of orthodontic brackets with larger slots may result in a three-dimensional loss of tooth placement.

Christy *et al*. [9] measured the dimensional accuracy of slot base width and slot top width of ten commercially available bracket systems. The authors found that the slot widths of all bracket systems significantly differed from each other. Using a stereomicroscope, Mathew *et al*. [1] evaluated the precision of the slot dimensions and built-in torque of seven upper right central incisor brackets of (MBT) prescription, they came to the conclusion that one should exercise caution when selecting a brand that is commercially available since some of the materials might not meet the required criteria.

Materials and Methods

A total of 33 upper left central incisor brackets were divided into 3 equal groups according to their manufacturing companies; (Dentaurum, American Orthodontic and Leone), then they were prepared to be scanned under SEM [1]; [Fig.1] from the lateral view. The collected photos were transferred to a specific software (Autodesk inventor[2]) which is a specific program that carried certain measurements of the slot dimension for each bracket.

Lateral view scan

1- Calculation of Bracket slot Height: The height of the slot was determined by placing two points at its corner base between vertical and horizontal base intersection, A1 and A2, and measuring the distance between them using a line. [Fig.2]
2- Calculation of bracket slot depth: Slot depth was measured by plotting two points on the internal wall of the bracket slot one at the bottom of the slot base corner between vertical and horizontal base intersection A1 and the other at the top of the slot wing A3 then connecting them with a line. [Fig.3]

All data were gathered, and collated, and statistical analysis was performed on them. SPSS [3] (version 20) is used for statistical analysis in general, and Microsoft Office Excel is utilised for data management and graphical presentation. Dahlberg error and Relative Dahlberg Error (RDE) are used in conjunction with Concordance Correlation Coefficients (CCC), including the 95% confidence limits of the coefficient, for both inter and intra observer reliability studies.

Eligibility criteria

The inclusion criteria

1) Pre-adjusted bracket system with 0.022 inch slot size MBT prescription.

The exclusion criteria

1) Bracket container not sealed.
2) Bracket has rust on its surface.
3) Bracket with broken wings.

Results

Most of the variables had a normal distribution. Few variables are slightly deviated from normality without obvious extreme values. Accuracy assessment for each group by using Parametric tests was held to define the relative mean error to the reference value as given by the manufacturer, it also showed the mean absolute error, standard deviation (SD), range (Minimum – Maximum), standard error (SR) and 95% confidence interval of the mean.

- Mean absolute errors are of the same units as the variable (inch for depth and height).
- The relative mean error is measured by dividing the mean absolute error by reference value.
- Variables with large relative error indicates poor accuracy

American Orthodontic system showed high relative mean error to the reference value, in slot depth (21.07%), in slot height (19.94%); which indicate a poor accuracy assessment among the other companies. (Table.1)

Dentaurum brackets system showed a relative mean error of all variable less than that of the American Orthodontic system, in slot depth (9.59%), in slot height (1.97%); which indicate an excellent accuracy assessment compared to the other companies. (Table 2)

Leone brackets system showed a relative mean error of all variable less than that of the American Orthodontic system, and larger than of the Dentaurum brackets system, it showed a slot depth (12.36%), in slot height (8.24%); which indicate a good accuracy assessment among the other companies. (Table 3)

For measuring the slot depth in each group and among the groups, one-way analysis of variance test, Anova test and multiple comparison Bonferroni method were done.

The dentaurum brackets system showed the lowest mean of absolute error (0.0021) while American Orthodontic brackets system showed the highest mean of absolute error (0.0046).

Leone brackets system showed a mean of absolute error (0.0027) which is less than the American Orthodontic brackets system and more than the Dentaurum brackets system. (Table.4) Anova test was held to compare the absolute error of depth among the three companies. Results show that there is a statistically high significant difference between the means of the slot depth absolute errors of the three systems. (Table.5)

Comparing the mean of slot depth between each 2 companies separately, it was found that the mean of slot depth is statistically significant higher in American than both Dentaurum and Leone brackets. Comparing Dentaurum to Leone brackets, the slot depth was statistically significant higher in Leone than Dentaurum. (Table.6)

For measuring the gap height in each group and among the groups One way analysis of variance test, Anova test and multiple comparison Bonferroni method were done.

Dentaurum brackets system showed the least mean of absolute error (0.0006) while American Orthodontic brackets system showed the highest mean of absolute error (0.0060).

Leone brackets system showed a mean of absolute error (0.0025) which is less than the American Orthodontic brackets system and more than the Dentaurum brackets system. (Table.7 & Fig. 4&5) Anova test was held to compare the absolute error of slot height among the three companies. Results revealed that there is a statistically high significant difference between the means of the gap height absolute errors of the three systems. (Table.8)

Comparing the mean of slot height between each 2 companies separately, it was found that the mean of slot height is statistically significant higher in American than both Dentaurum and Leone brackets. Comparing Dentaurum to

[1] Zeiss EVO MA10 model, Oberkochen, Germany.
[2] Inventor® 3D CAD software provides professional-grade mechanical design, documentation, and product simulation tools. establishments in California - USA.
[3] SPSS: one of IBM software programs, New York- USA.

Leone brackets, the slot height was statistically significantly higher in Leone than Dentaurum. (Table.9 & Fig.6 & 7)

Summarizing the Results

1. When compared to the standard MBT prescribed values, Group II (Dentaurum) showed the least variance in slot height of the samples under scanning electron microscopy, and Group I (American Orthodontics) showed the most variation. All of the brackets' actual slot heights were higher at the entry than they were at the base, indicating that they were divergent.
2. When comparing the slot depth of the samples under a scanning electron microscope to the values recommended by the standard MBT, Group II (Dentaurum) had shown least variation and Group I (American Orthodontics) displayed the most variation. Nearly all of the brackets, when assessed for slot depth, were undersized.

Discussion

The necessary goal of orthodontic treatment has always been to achieve ideal occlusion that is both aesthetically pleasing and functionally efficient. By offering precise control over the movement of teeth in all three planes of space, the orthodontic bracket plays a critical role in accomplishing that goal. An optimal tooth position has been programmed into the brackets to allow for precise manipulation; referred to as a bracket prescription. The play of the wire within the slot and the manufacturer's tolerance of the wire and slot are factors that affect the bracket prescription. Standardization is a crucial component of technical advancement. According to the manufacturer's prescription, pre-adjusted edgewise orthodontic brackets are precisely made, enabling predictable three-dimensional tooth movement. There are countless manufacturers and virtually infinite variations in bracket designs available. Despite the importance of bracket prescription in orthodontic treatment, little research has been done on the tolerances of the bracket slot, which are crucial when utilizing a pre-adjusted appliance.

In the current study when the slot height was measured, it was found that Group II (Dentaurum) value was the closest to the average prescribed value ($p \leq 0.05$), whereas Group I (American Orthodontic) brackets had the most variance from the average ($p \leq 0.05$). The differences in slot height dimensions between each bracket and the reference values were all statistically significant.

The findings of our study coincide with those of Christy *et al.* [9] who measured the dimensional accuracy of slot base width and slot top width of 0.022-inch upper right central incisor They noticed that all bracket systems slot heights were smaller than the manufacturer's recommended size. Additionally, using a stereomicroscope, Mathew *et al.* [1] measured the precision of bracket slot dimensions and built-in torque of seven upper right central incisor brackets of (MBT) prescription with 0.022-inch The authors also reported that every bracket under examination was larger than the manufacturer's recommended size.

On examining the slot depth, we discovered that Group II (Dentaurum) values were statistically significant and closest to the standard value ($p \leq 0.05$), while Group I brackets (American) displayed greater variation when compared to the standard values. With 100% of the brackets being undersized, every bracket displayed a statistically significant deviation in slot depth dimension from the standard values.

It was reported that changes in both slot height & depth could be largely attributed to manufacturing errors. Errors in either the milling or the injection processes may lead to either shrinkage or expansion of the manufactured brackets.

The findings of the current study show that no manufacturer provided brackets with the precise dimensions required by the standard MBT recommended values. The bracket prescriptions' detected errors may result in inappropriate occlusion, an unfavourable interincisal angle that negatively affects the overjet, overbite and stability of the orthodontic therapy due to injudicious finishing & detailing of occlusion.

The pre-adjusted bracket systems and prescriptions utilized in clinical practice should be completely understood and unveiled by the orthodontist. Orthodontists should know when to correct the incisor inclination and when to accept it. Well-trained orthodontists should learn how to get around the incorrect manufacturing dimensions. Despite using a straight wire appliance, orthodontists must be capable & acquainted with wire bending throughout all the stages of treatment.

Fig 1: Scanning Electron Microscope (SEM) model (Zeiss EVO MA10)

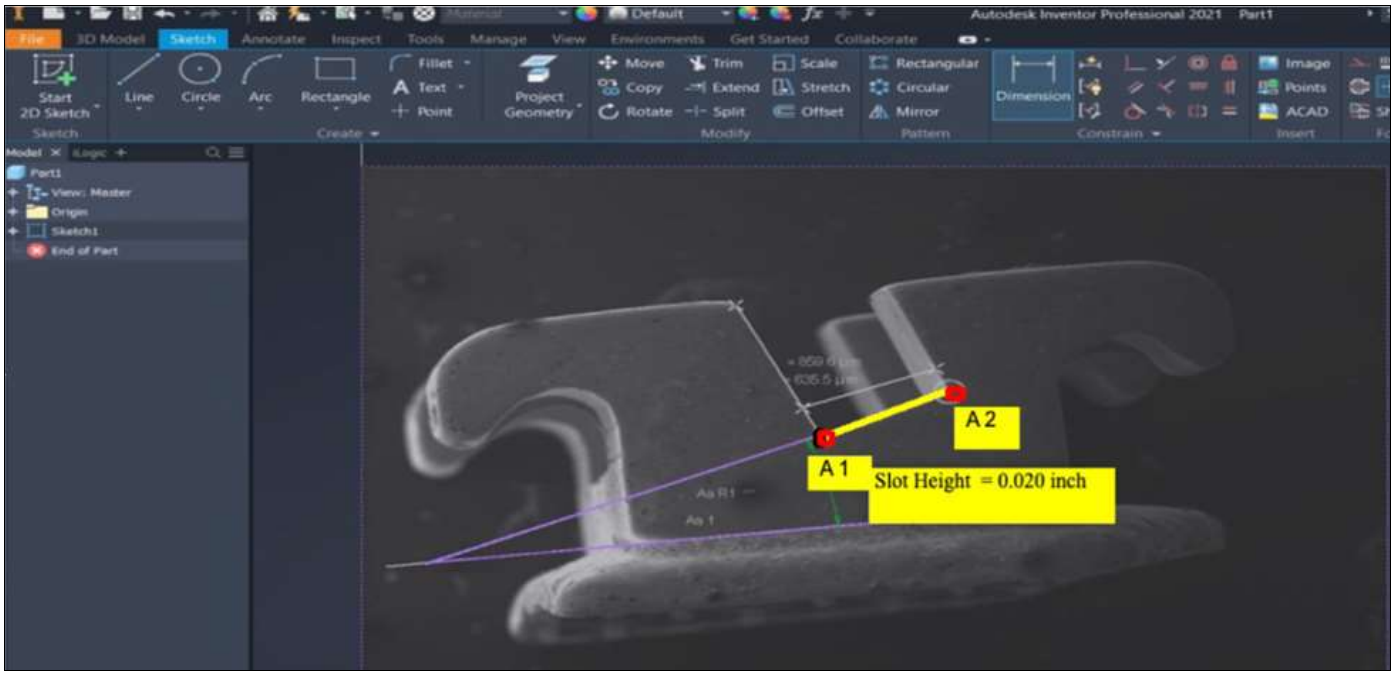

Fig 2: An image from Autodesk inventor software showing a lateral view of upper left central incisor (Dentaurum) measuring the slot height with the two reference points A1 and A2

Fig 3: An image from Autodesk inventor software showing a lateral view of upper left central incisor (Dentaurum) measuring the slot depth with the two reference points A1 and A3

Table 1: Descriptive statistic showing the Accuracy assessment of American brackets for all measurements

	N	Mean Absolute error	SD	SEM	95% Confidence Interval for Mean		Minimum	Maximum	Relative mean error to the reference value
					Lower Bound	Upper Bound			
Absolute error of slot depth	11	**0.0046**	0.0009	0.0003	0.0040	0.0052	0.0040	0.0064	**21.07%**
Absolute error of slot height	11	**0.0060**	0.0012	0.0004	0.0052	0.0068	0.0038	0.0074	**19.94%**

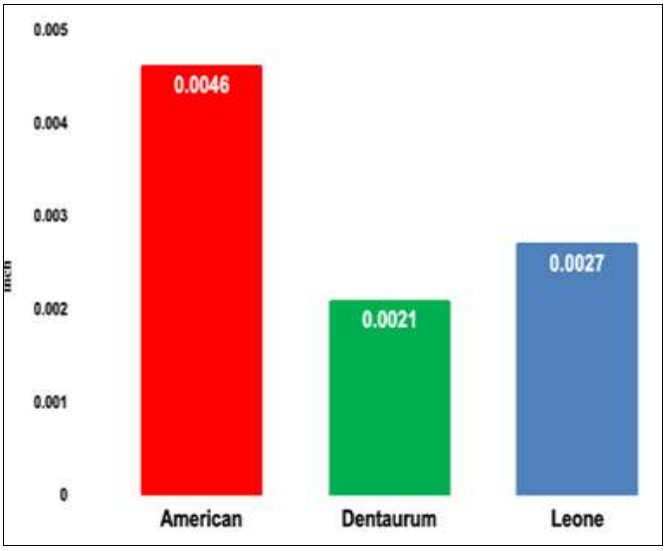

Fig 4: Bar chart showing mean absolute error of slot width

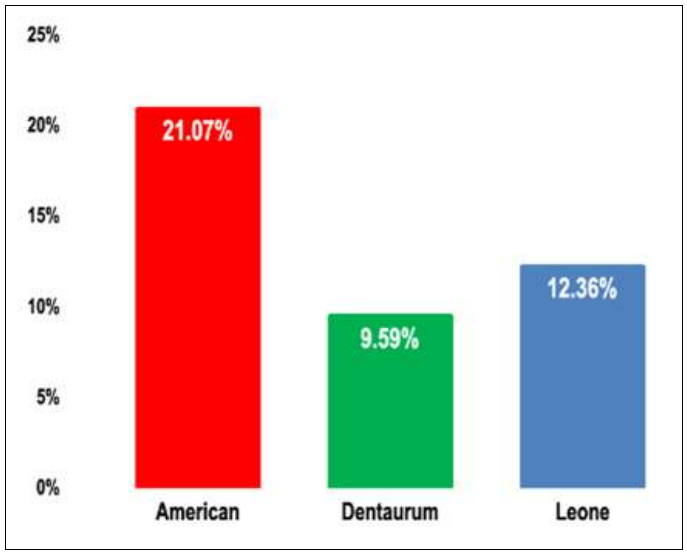

Fig 5: Bar chart showing relative error of slot width

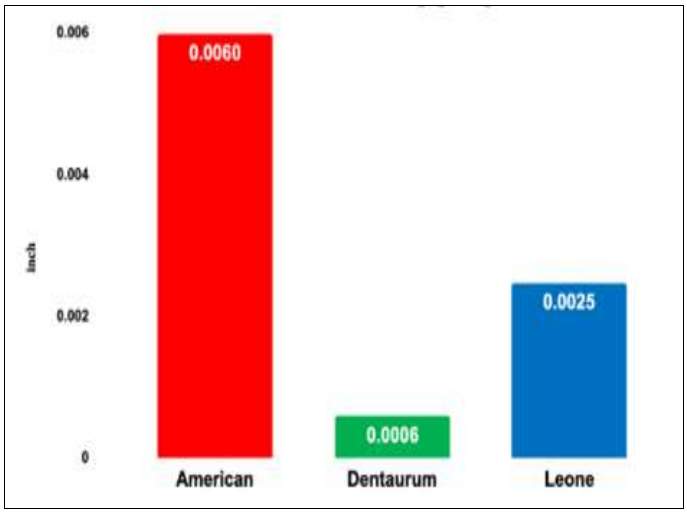

Fig 6: Bar chart showing mean absolute error of slot height

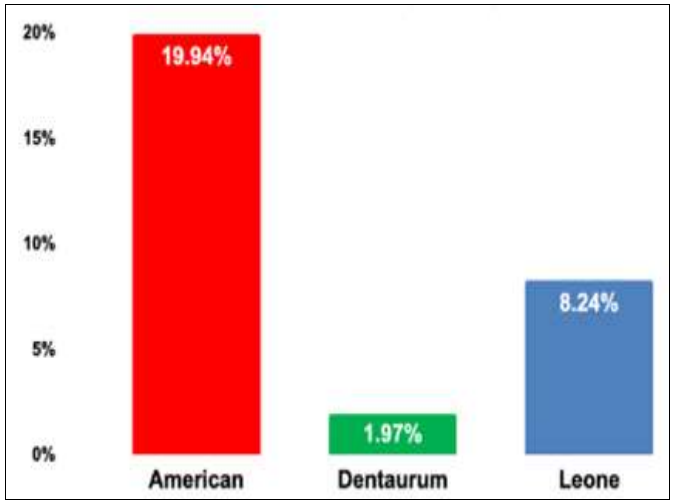

Fig 7: Bar chart showing relative error of slot height

Table 2: Descriptive statistic showing the Accuracy assessment of Dentaurum brackets for all measurements

	N	Mean Absolute error	SD	SEM	95% Confidence Interval for Mean		Minimum	Maximum	Relative mean error to the reference value
					Lower Bound	Upper Bound			
Absolute error of slot depth	11	**0.0021**	0.0001	0.0000	0.0020	0.0022	0.0020	0.0024	**9.59%**
Absolute error of slot height	11	**0.0006**	0.0007	0.0002	0.0001	0.0011	0.0000	0.0023	**1.97%**

Table 3: Descriptive statistic showing the Accuracy assessment of Leone brackets for all measurements

	N	Mean Absolute error	SD	SEM	95% Confidence Interval for Mean		Minimum	Maximum	Relative mean error to the reference value
					Lower Bound	Upper Bound			
Absolute error of gap depth	11	**0.0027**	0.0004	0.0001	0.0025	0.0030	0.0021	0.0032	**12.36%**
Absolute error of gap height	11	**0.0025**	0.0010	0.0003	0.0018	0.0031	0.0010	0.0043	**8.24%**

Table 4: Descriptive statistics for the absolute error of slot depth between the 3 systems using Way Analysis of Variance

	N	Mean Absolute error	SD	SEM	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
American	11	**0.0046**	0.0009	0.0003	0.0040	0.0052	0.0040	0.0064
Dentaurum	11	**0.0021**	0.0001	0.0000	0.0020	0.0022	0.0020	0.0024
Leone	11	**0.0027**	0.0004	0.0001	0.0025	0.0030	0.0021	0.0032

Table 5: Showing Anova test for absolute error of slot depth

		Sum of Squares	df	Mean Square	F	P Value	
Absolute error of slot depth	Between Groups	0.000038	2	0.000019	59.980	0.00000	**P < 0.001 HS**
	Within Groups	0.000010	30	0.000000			
	Total	0.000048	32				

Table 6: Showing multiple comparisons Bonferroni method of slot depth:

		Mean Difference	Std. Error	P Value	95% Confidence Interval		
					Lower Bound	Upper Bound	
American	**Dentaurum**	0.00253	.00024	0.00000	.0019	.0031	**P < 0.001 HS**
American	**Leone**	0.00192	.00024	0.00000	.0013	.0025	**P < 0.001 HS**
Dentaurum	**Leone**	-.00061	.00024	0.05080	-.0012	.0000	**P =~ 0.05 Almost S**

Table 7: Descriptive statistics for the absolute error of slot height between the 3 systems using One Way Analysis of Variance

	N	Mean Absolute error	SD	SEM	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
American	11	**0.0060**	0.0012	0.0004	0.0052	0.0068	0.0038	0.0074
Dentaurum	11	**0.0006**	0.0007	0.0002	0.0001	0.0011	0.0000	0.0023
Leone	11	**0.0025**	0.0010	0.0003	0.0018	0.0031	0.0010	0.0043

Table 8: Showing Anova test for absolute error of slot height

		Sum of Squares	df	Mean Square	F	P Value	
Absolute error of gap height	Between Groups	0.000165	2	0.000082	84.065	0.00000	**P < 0.001 HS**
	Within Groups	0.000029	30	0.000001			
	Total	0.000194	32				

Table 9: Showing multiple comparisons Bonferroni method of slot height

		Mean Difference	Std. Error	P Value	95% Confidence Interval		
					Lower Bound	Upper Bound	
American	**Dentaurum**	0.00539	.00042	0.00000	.0043	.0065	**P < 0.001 HS**
American	**Leone**	0.00351	.00042	0.00000	.0024	.0046	**P < 0.001 HS**
Dentaurum	**Leone**	-.00188	.00042	0.00032	-.0030	-.0008	**P < 0.001 HS**

Conclusion

On the basis of the results obtained from the present *in-vitro* study, the following conclusions can be drawn:

1. In the current study, it was found that the actual dimensions of tested brackets were significantly different from what was claimed by all three companies.

2. It was found that there was considerable variation in the slot sizes between different bracket systems.

Conflict of Interest
Not available

Financial Support
Not available

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